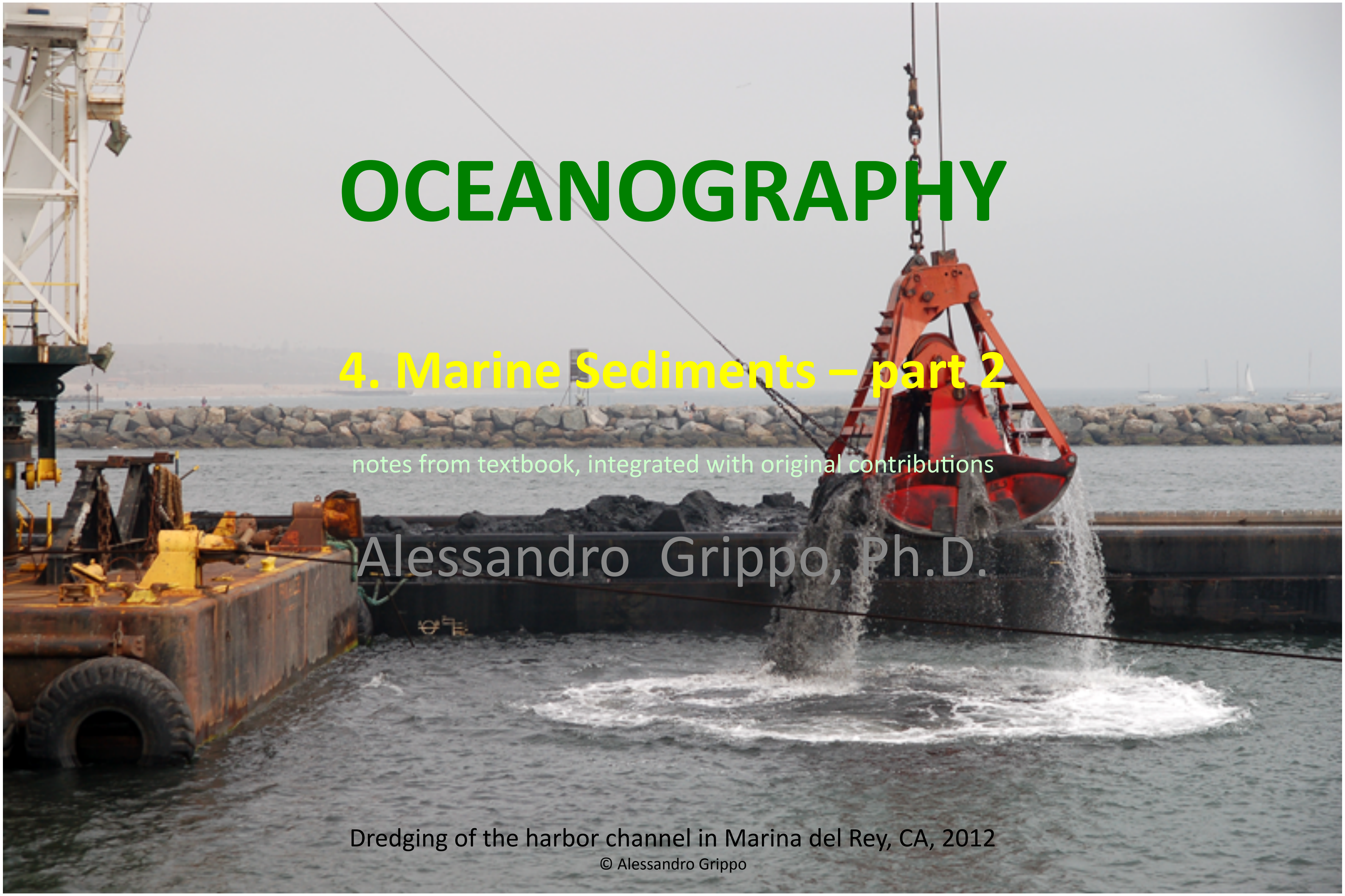
OCEANOGRAPHY

4. Marine Sediments – part 2

notes from textbook, integrated with original contributions

Alessandro Grippo, Ph.D.



Dredging of the harbor channel in Marina del Rey, CA, 2012

4.2 – What Are the Characteristics of Biogenous Sediment?

- Hard remains of once-living organisms (fossils)

- Two major types:
  - Macroscopic
    - Visible to naked eye
    - Shells, bones, teeth
    - Rare, except for a few tropical beaches
  - Microscopic
    - Visible under a microscope
    - Tiny shells or tests
    - Biogenic ooze

- The most common organisms that produce biogenous sediment (fossil remains) are microscopic
  - algae
  - protozoans (protists)

Macrofossils vs. Microfossils

- Macrofossils are visible
  - Most fossils in museums are macrofossils
- Microfossils can only be seen with a microscope
  - Microfossils are more common, tend to remain intact, and provide more information than macrofossils

Macrofossils

Tyrannosaurus rex
Royal Tyrrell Museum
Drumheller, Alberta

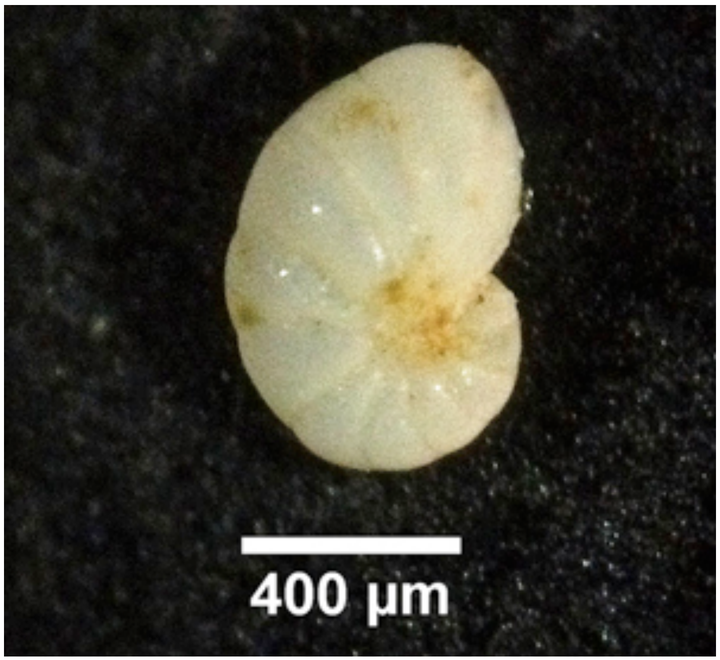
Elephas primigenius
George C. Page Museum, La Brea Tar Pits,
Los Angeles, California

Macrofossils

Turritella
Big Bend National Park
Terlingua, Texas

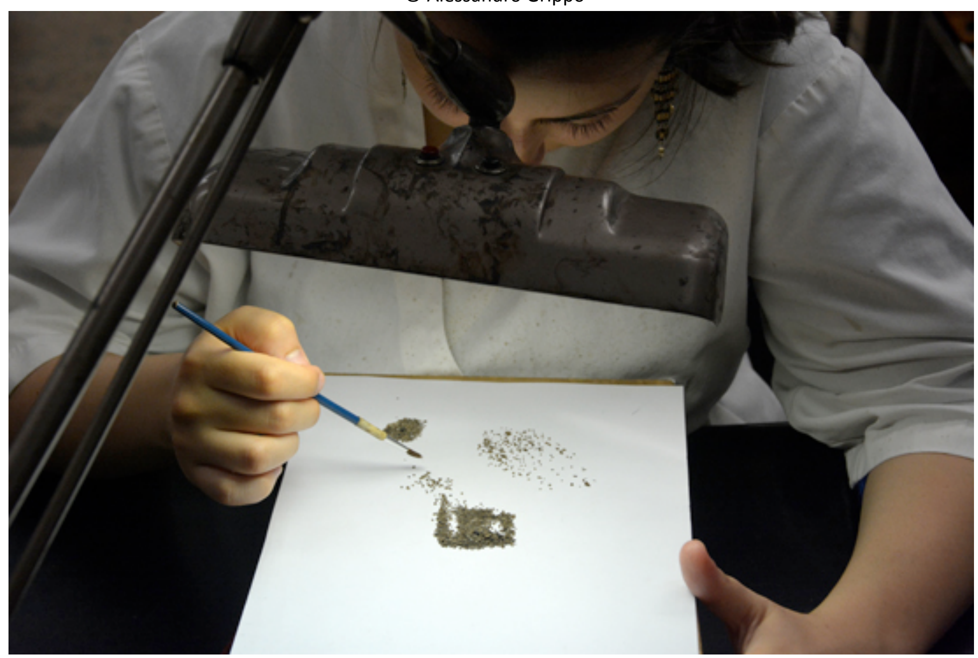
Cycadoidea etrusca
"found in an Etruscan tomb in Marzabotto"
Museum of Geology and Paleontology
Universitá di Bologna, Bologna, Italy

Microfossils



Florilus chesapeakensis, Miocene
Randle Cliff Beach, Maryland
From the blog [Fossils and Other Living Things]

A micropaleontologist at work with microfossils at the George C. Page Museum, La Brea Tar Pits
Los Angeles, California



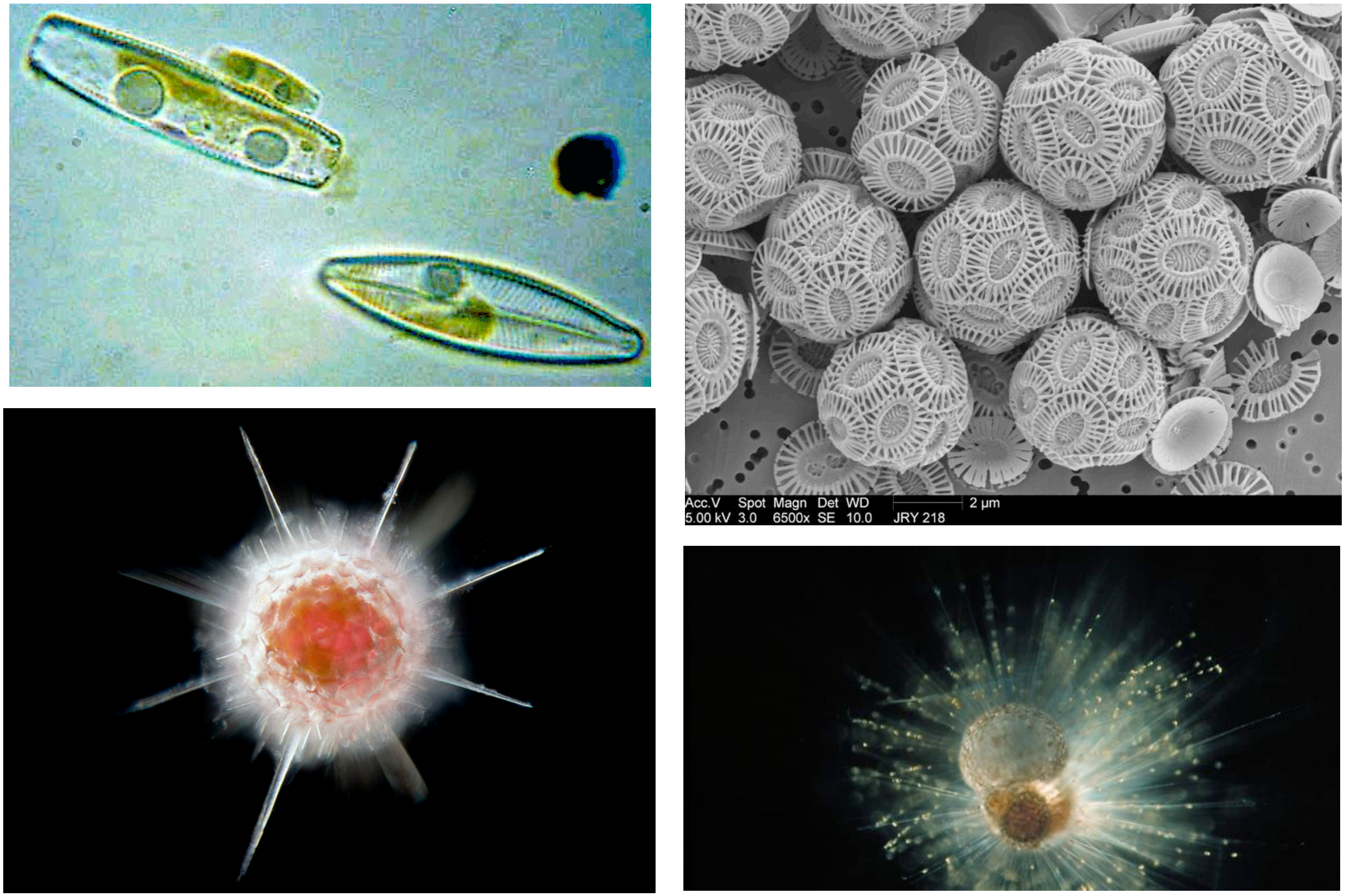
Biogenous Sediment composition

- Two most common chemical compounds:
  - Calcium carbonate ($CaCO_3$)
  - Silica (SiO_2), often found in its hydrated form Opal ($SiO_2 \cdot nH_2O$)

- Include many kinds of single-celled organisms and a few kinds of simple multicellular organisms

- Plant-like protists (algae) are photosyntehtic
  - dinoflagellates, diatoms, coccolithophores
    - all these are very important in the fossil record

- Animal-like protists (or protozoans)
  - amoebas, zooflagellates, ciliates
    - radiolarians and foraminifera are amoeba-like protists that are also very important in the fossil record



Clockwise from upper left: live Diatoms; Coccolithophores; live Foraminifer; live Radiolarian

Nekton, Benthos, Plankton

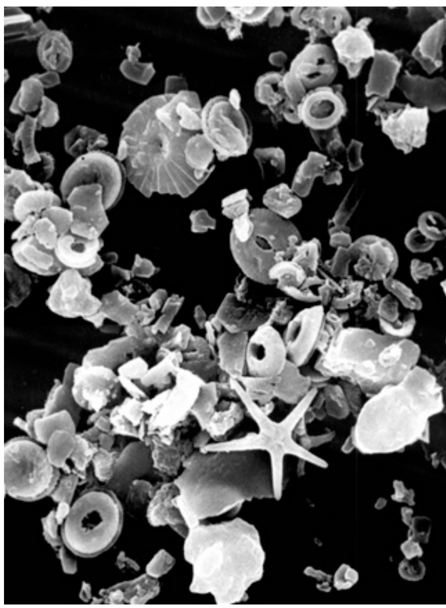
- Organisms that live in the ocean can be classified as:
  - **Nekton**: swimmers
    - example: dolphins, octopuses, squids, whales
  - **Benthos**: bottom dwellers
    - sessile (standing in one place, like a tree on land)
      - example: sea lilies
    - mobile (on the surface – **epifauna**; digging into the substrate – **infauna**)
      - example: crabs and lobsters
  - **Plankton**: floaters

Important Planktonic Protists in the fossil record

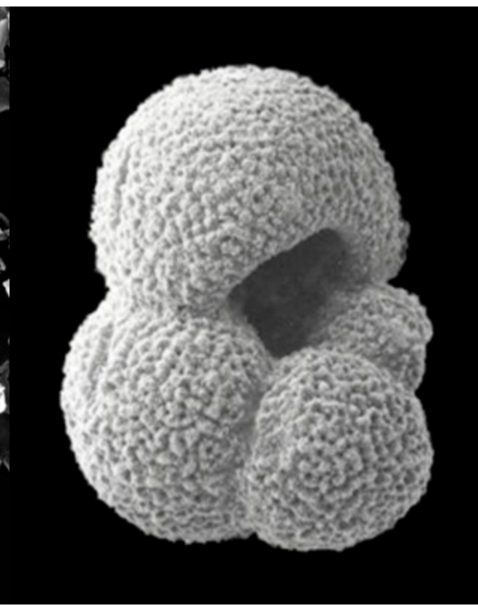
- **Phytoplankton** (plant-like)
  - Diatoms and Coccolithophores
- **Zooplankton** (animal-like)
  - Radiolarians and Foraminifera
- These organisms secrete a skeleton (also called a “test”, or a shell)
- When they die, these skeletons sink to the bottom of the ocean and form a rock

All these organisms are microscopic: they can only be observed under a microscope.
Coccolithophores are so small that they can only be imaged with a SEM (Scanning Electron Microscope)

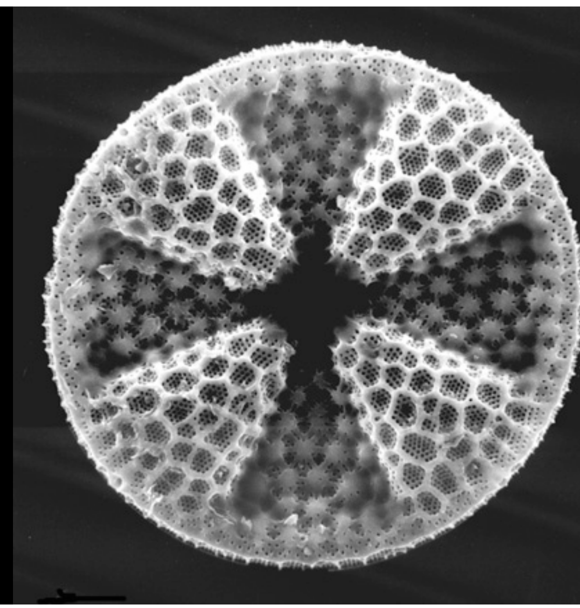
	$CaCO_3$ shell	SiO_2 shell
Phytoplankton	**Coccoliths** (disks from Coccolithophores)	**Diatoms**
Zooplankton	**Foraminifera**	**Radiolarians**



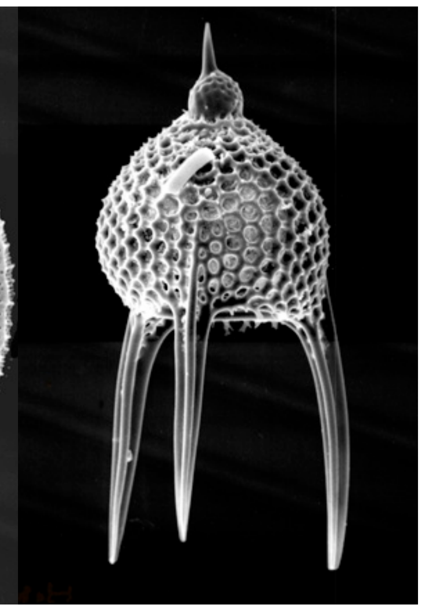
Coccoliths



Foraminifer



Diatom

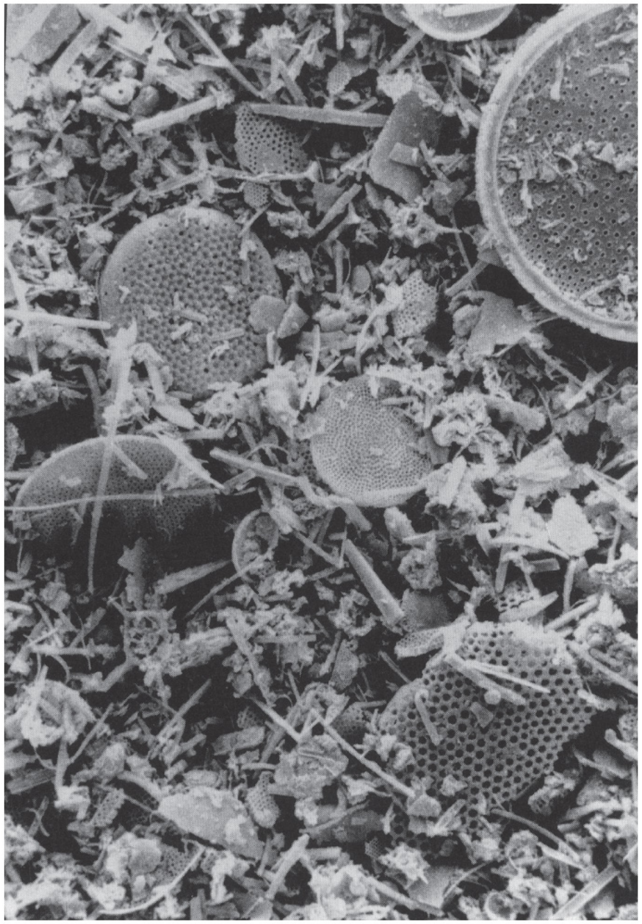


Radiolarian

Silica in Biogenous Sediments

- Tests from diatoms and radiolarians generate siliceous ooze.

- Siliceous ooze lithifies into diatomaceous earth and radiolarites

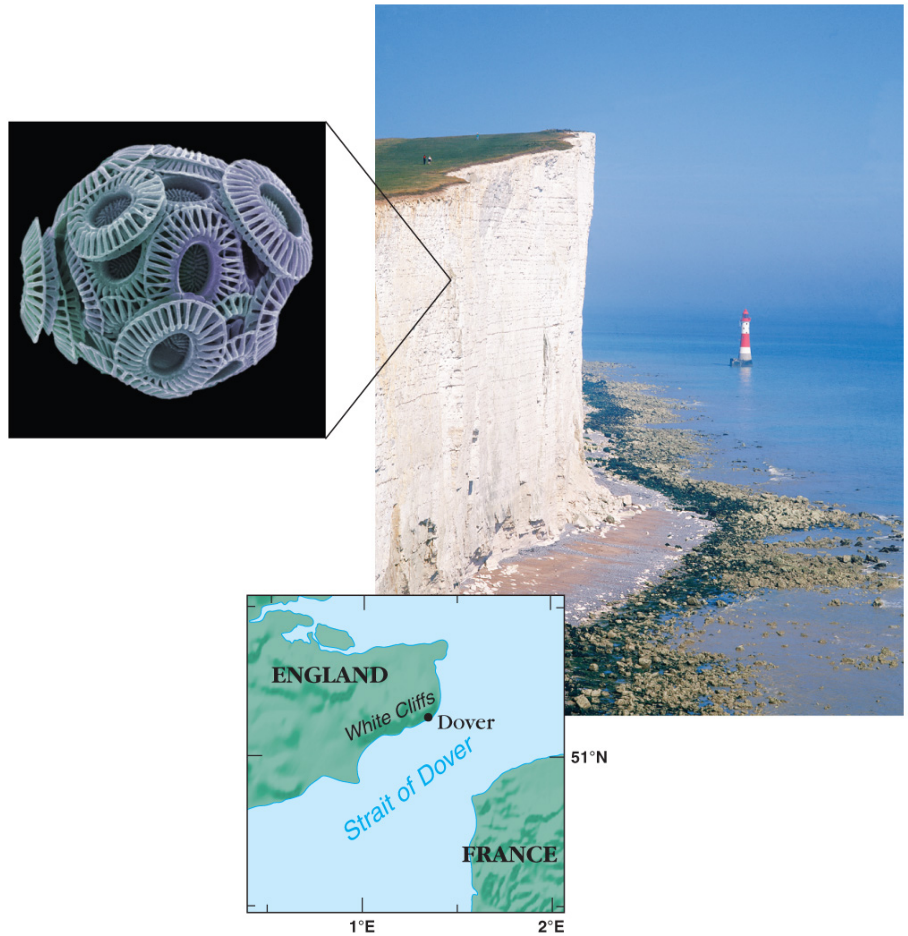


(c)

Calcium Carbonate in Biogenic Sediments

- Tests from Coccolithophores and Foraminifera will form a calcareous ooze

- Coccolithophores
  - Also called *nannoplankton*
  - Photosynthetic algae
  - Coccoliths – individual plates from dead organism
  - Chalk
    - Lithified coccolith-rich ooze

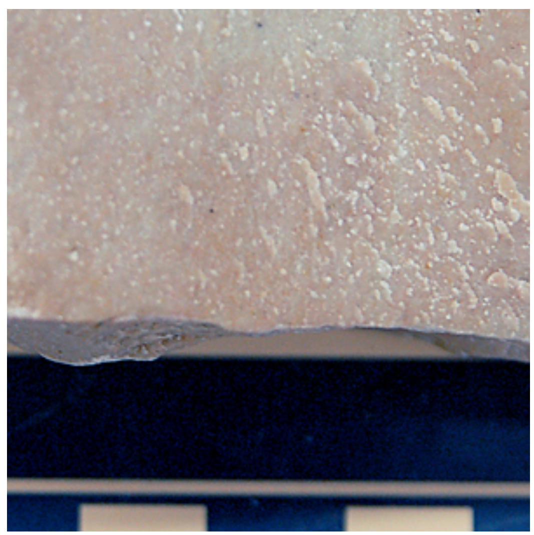


- Foraminifera
  - Protozoans (zooplankton)
  - Use external food
  - Also form foraminifer ooze
  - Can be mixed up with coccoliths

  - Micrite, or micritic limestone
  - If mixed 35-65% with abyssal claya, rocks are called Marls

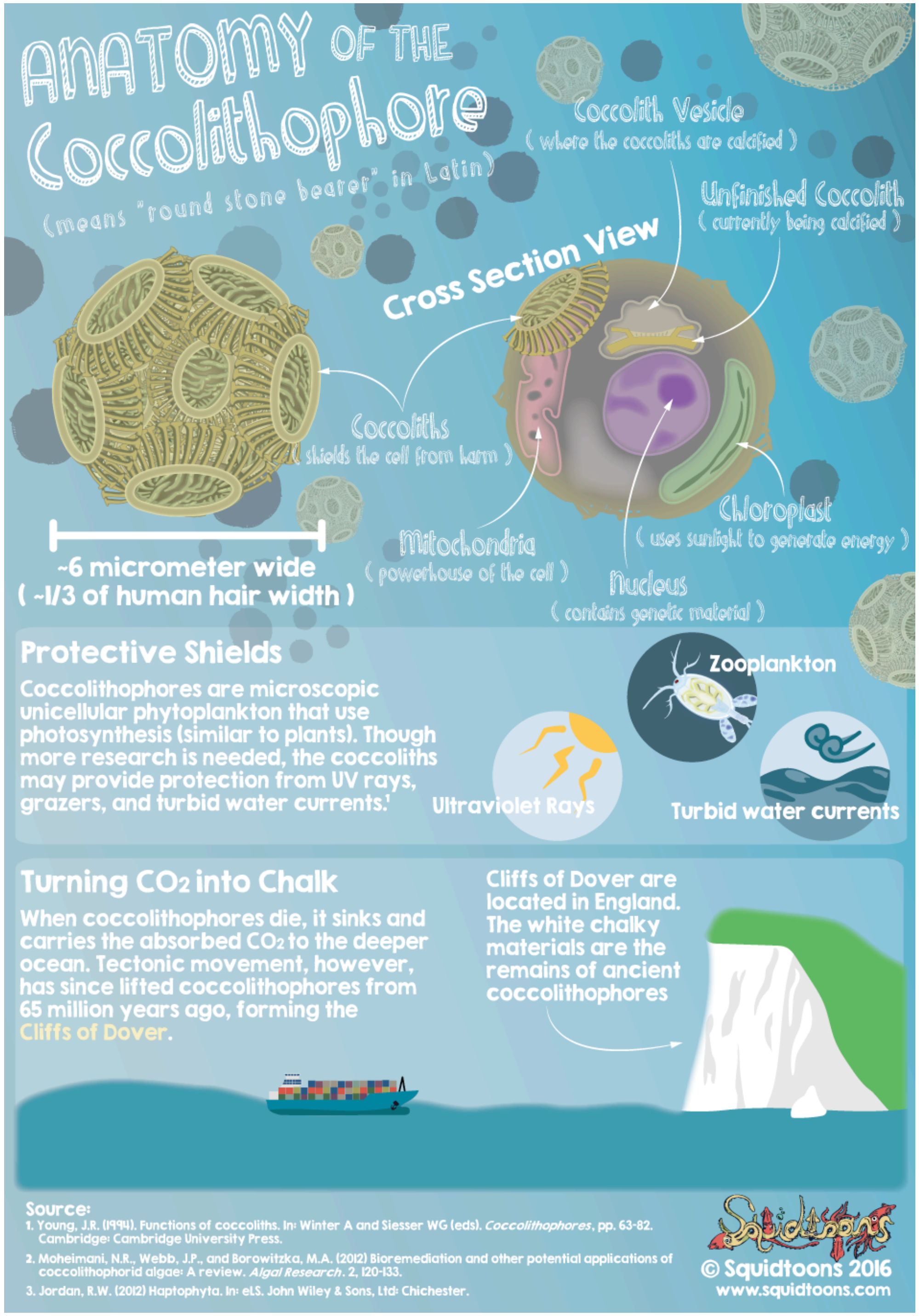
(c)

Chalk



Micrite

Chert



ANATOMY OF THE Coccolithophore
(means "round stone bearer" in Latin)
Cross Section View
Coccolith Vesicle
(where the coccoliths are calcified)
Unfinished Coccolith
(currently being calcified)
Coccoliths
(shields the cell from harm)
Mitochondria
(powerhouse of the cell)
Chloroplast
(uses sunlight to generate energy)
Nucleus
(contains genetic material)
~6 micrometer wide
(~1/3 of human hair width)
Protective Shields
Coccolithophores are microscopic unicellular phytoplankton that use photosynthesis (similar to plants). Though more research is needed, the coccoliths may provide protection from UV rays, grazers, and turbid water currents.[1]
Ultraviolet Rays
Zooplankton
Turbid water currents
Turning CO2 into Chalk
When coccolithophores die, it sinks and carries the absorbed CO2 to the deeper ocean. Tectonic movement, however, has since lifted coccolithophores from 65 million years ago, forming the Cliffs of Dover.
Cliffs of Dover are located in England. The white chalky materials are the remains of ancient coccolithophores
Source:
1. Young, J.R. (1994). Functions of coccoliths. In: Winter A and Siesser WG (eds). Coccolithophores, pp. 63-82. Cambridge: Cambridge University Press.
2. Moheimani, N.R., Webb, J.P., and Borowitzka, M.A. (2012) Bioremediation and other potential applications of coccolithophorid algae: A review. Algal Research. 2, 120-133.
3. Jordan, R.W. (2012) Haptophyta. In: eLS. John Wiley & Sons, Ltd: Chichester.
© Squidtoons 2016
www.squidtoons.com

Chalk from pelagic coccolith oozes: The K/Pg boundary at Stevns Klimt, Denmark

Distribution of Biogenous Sediments

- Depends on three processes:
  - Productivity
    - Number of organisms present in surface waters
    - depends on availability of food and light (photosynthesis can be effective only in the photic zone, that is the first 100 m of the ocean form the surface)
  - Destruction
    - Many tests are dissolved at the bottom or even before reaching it
  - Dilution
    - When other kinds of sediments are present, they *dilute* the oozes
    - Typically it is lithogenous sediment that dilutes oozes
    - Since lithogenous sediment is common in coastal areas, biogenous sediment is more indicative of deep-waters

Biogenous Sediment: neritic deposits

- neritic deposits are dominated by lithogenous sediments

- in certain areas, particularly in shallow tropical waters, carbonate deposits (biogenous sediment) are abundant
  - Carbonate minerals containing CO_3
  - Marine carbonates primarily limestone – $CaCO_3$
  - Most limestones contain fossil shells
    - Suggests biogenous origin
  - Ancient marine carbonates constitute 25% of all sedimentary rocks on Earth.

- Coral Reefs
  - Massive structure of carbonate
  - Warm, crystal-clear, shallow waters
  - Atolls, Barriers, Fringing Reefs

- Stromatolites
  - Fine layers of carbonate
  - Warm, shallow-ocean, high salinity
  - Cyanobacteria

(a)

The Great Barrier Reef of Australia

from Cyanobacteria to Stromatolites

- Some filamentous cyanobacteria float as greenish scum on lake, streams, or ocean waters

- Others form “algal” mats on the seafloor that can trap sediment to produce distinctive 3-D structures (stromatolites)

Modern Stromatolites from Shark Bay, Australia

Stromatolites

in four "simple" steps

① **Accretionary organosedimentary structures**

the structure build up (accretes), and forms a structure through interaction of biological and physical processes

② **commonly thin-layered, megascopic, and calcareous**

made of thin, stacked laminae, visible to the naked eye, partially composed of calcium carbonate minerals

③ **produced by the activity of mat-building communities of mucilage-secreting microorganisms**

microscopic organisms living together generate mats, or layers by secreting sticky gelatin-like slime

④ **mainly filamentous photoautotrophic prokaryotes such as cyanobacteria**

most organisms are developing threads (and not spheres), are photosynthetic, are Bacteria and Archaea, and most of the times are cyanobacteria

Fossil Stromatolites

from Glacier National Park, Montana

Calcareous Ooze and the CCD

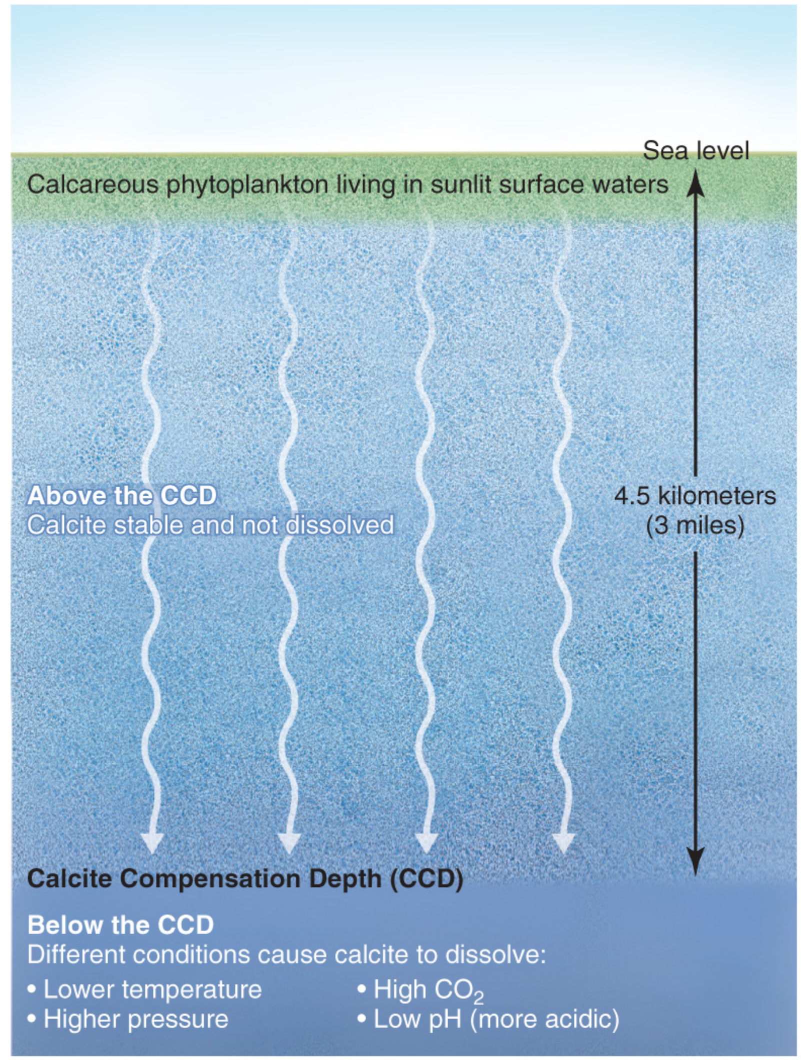
- CCD – Calcite (or Carbonate) compensation depth
  - Depth where $CaCO_3$ readily dissolves
  - *Rate of supply = rate at which the shells dissolve*

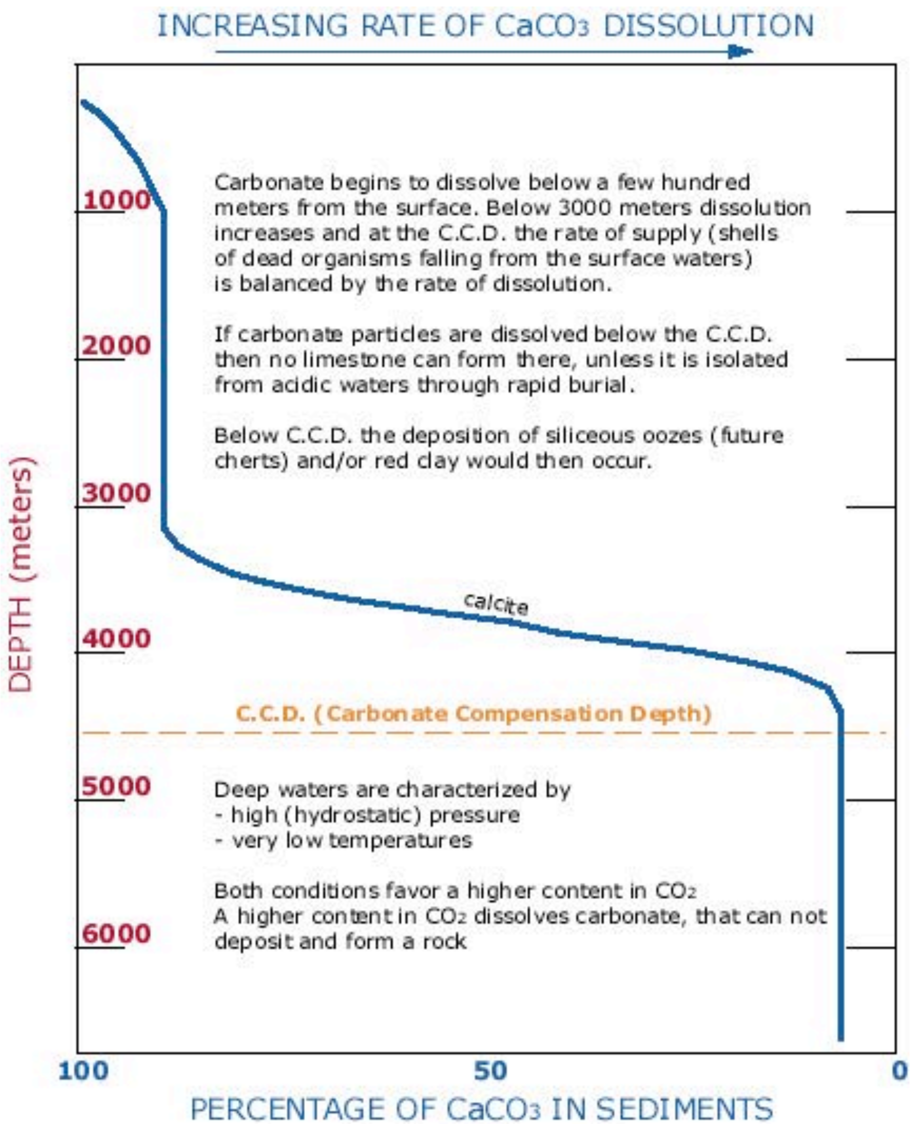
- Warm, shallow ocean saturated with calcium carbonate
- Cool, deep ocean undersaturated with calcium carbonate

- Equilibrium reaction of calcite in water:
  - $CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$

$$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$$

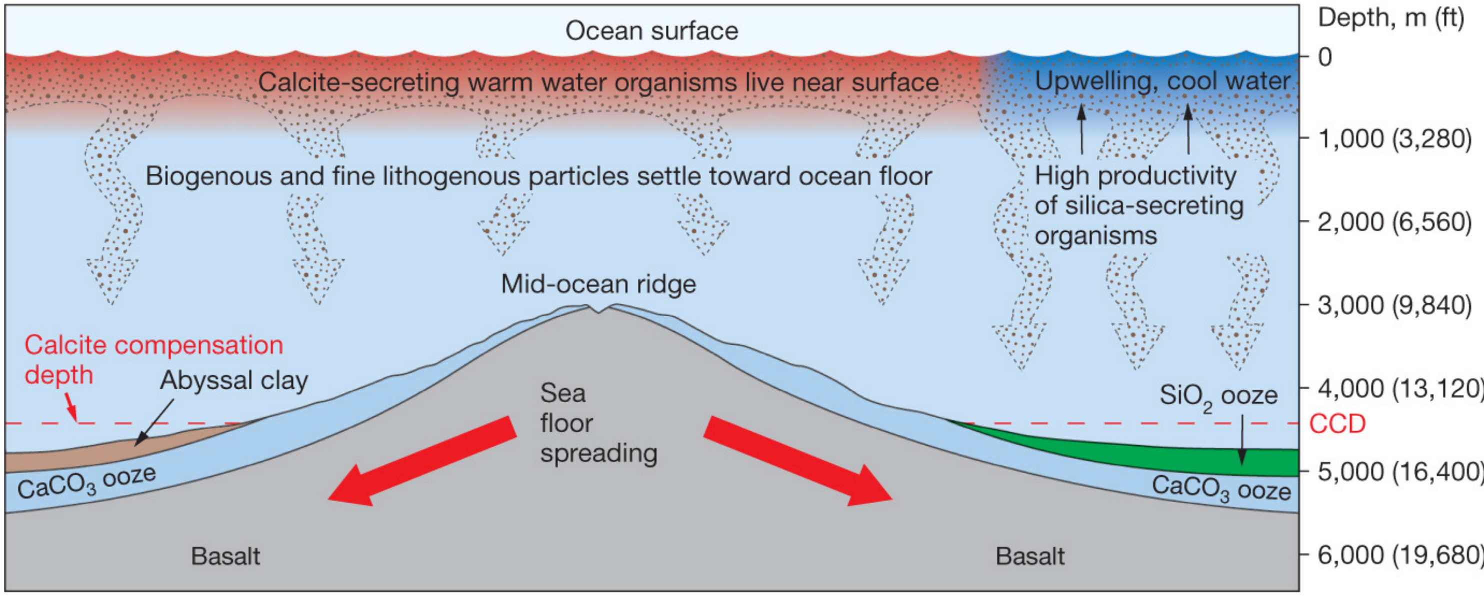
- CO_2 dissolves $CaCO_3$
- CO_2 stays in water with high pressure and low temperatures
  - conditions found in deep-ocean waters and shallow temperate to polar waters
  - $CaCO_3$ shells dissolve
- CO_2 leaves water with low pressure and high temperatures
  - conditions found in shallow tropical waters
  - $CaCO_3$ forms naturally
  - "Carbonate Factory"

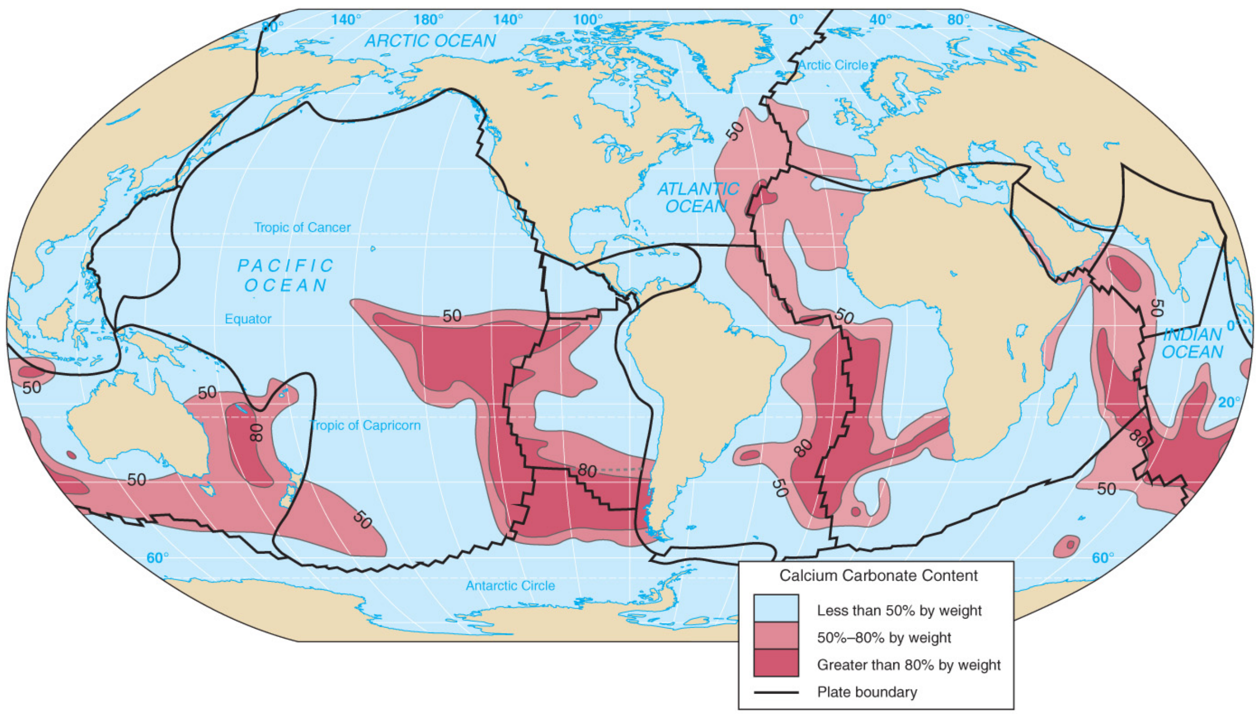




- Lysocline – depth at which *a significant amount of* $CaCO_3$ begins to dissolve rapidly

- Scarce calcareous ooze below 5000 meters (16,400 feet) in modern ocean
- Ancient calcareous oozes at greater depths if moved by sea floor spreading


Ocean surface
Depth, m (ft)
0
1,000 (3,280)
2,000 (6,560)
3,000 (9,840)
4,000 (13,120)
5,000 (16,400)
6,000 (19,680)
Calcite-secreting warm water organisms live near surface
Upwelling, cool water
Biogenous and fine lithogenous particles settle toward ocean floor
High productivity of silica-secreting organisms
Mid-ocean ridge
Calcite compensation depth
Abyssal clay
$CaCO_3$ ooze
Sea floor spreading
SiO_2 ooze
CCD
$CaCO_3$ ooze
Basalt
Basalt


ARCTIC OCEAN
Arctic Circle
ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Calcium Carbonate Content
Less than 50% by weight
50%–80% by weight
Greater than 80% by weight
Plate boundary

4.4 – What Are the Characteristics of Hydrogenous Sediment?

- Chemical reactions in the ocean can cause minerals to precipitate directly from seawater

- Reactions usually happen because of changes in the ocean (P, T, salinity, different fluids, etc.)

  - Manganese nodules
  - Phosphates
  - Carbonates
  - Metal sulfides

- Small proportion of marine sediments
- Distributed in diverse environments

Manganese Nodules

- Fist-sized lumps of manganese, iron, and other metals, often with layered internal structure
- Many commercial uses
- Unsure why they are not buried by seafloor sediments
  – Lack of other types of sediment
  – Bacterial action?
  – Very slow accumulation rates
  – Form in spurts, rather than steadily

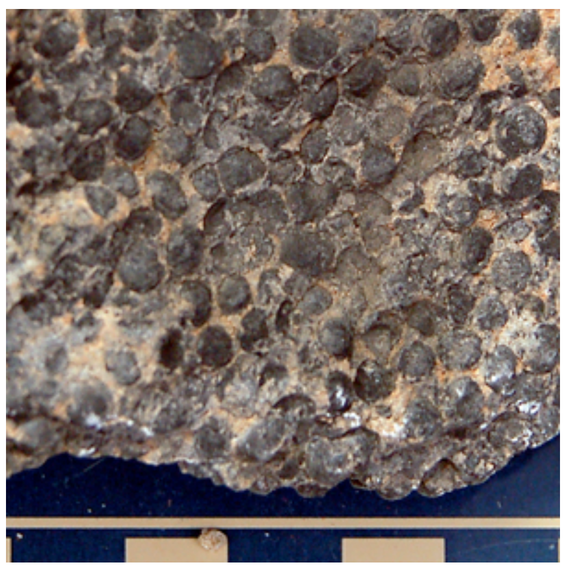
(a)

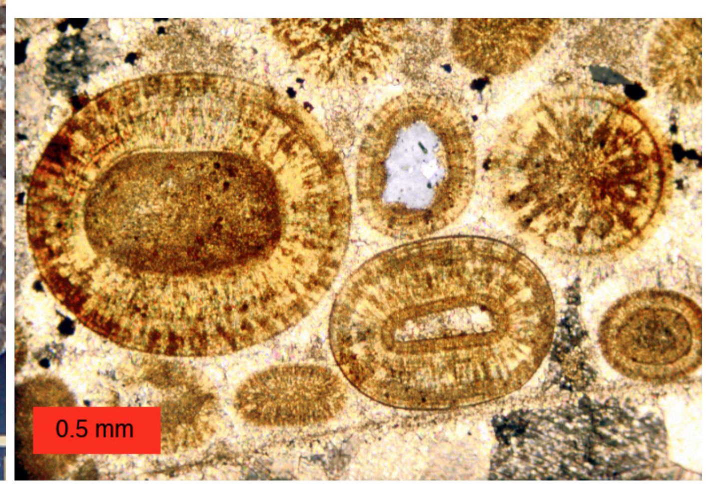
Phosphates and Carbonates

- Phosphates
  - Phosphorus-bearing (PO4 2- ions)
  - Occur beneath areas in surface ocean of very high biological productivity
  - Economically useful as fertilizer
- Carbonates
  - Aragonite and calcite
  - Oolites

Left and center: oolitic limestones
(SMC Geology collection)

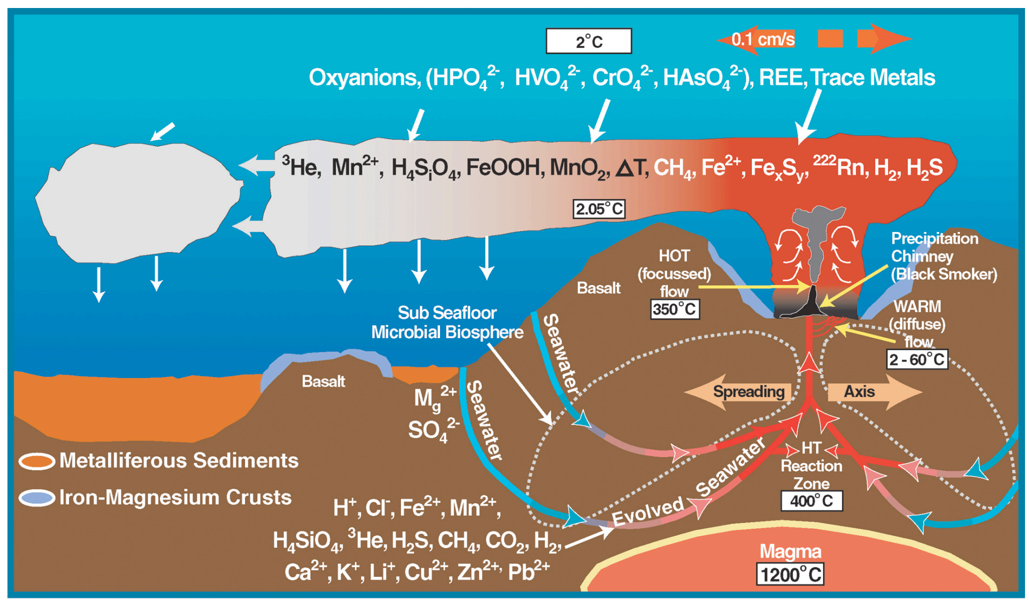
Right: oolitic limestone thin section
(University of Maryland)





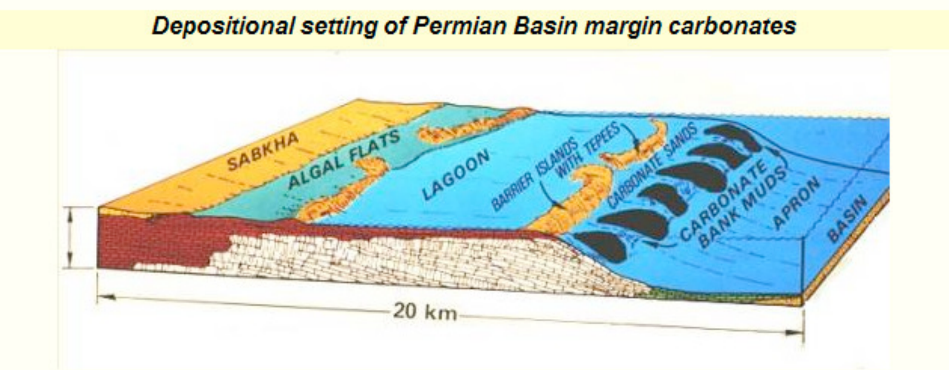
Metal Sulfides

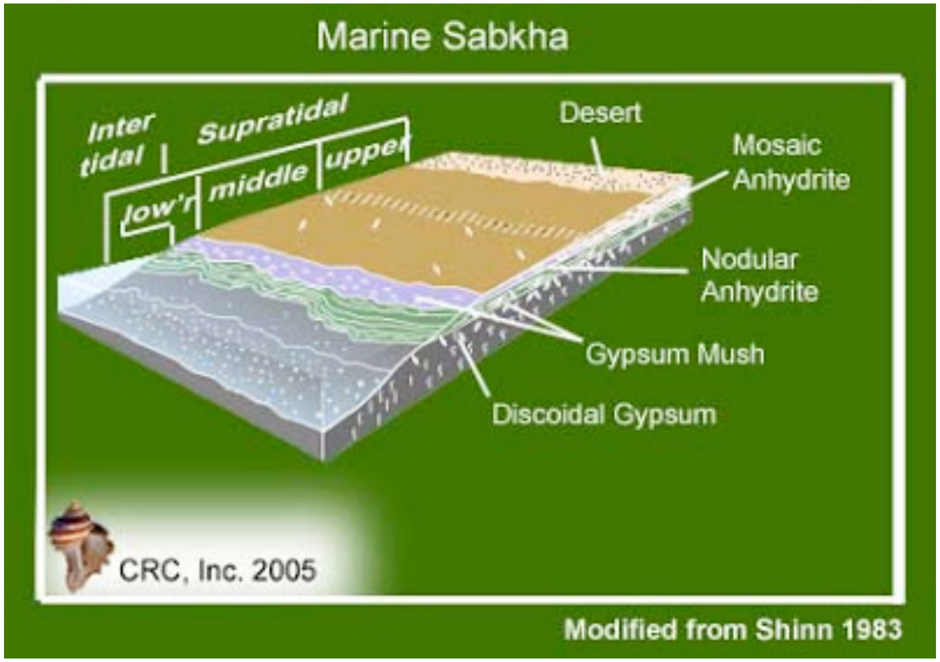
- Metal sulfides
  - Contain:
    - Iron (Fe)
    - Nickel (Ni)
    - Copper (Cu)
    - Zinc (Zn)
    - Silver (Ag)
    - Other metals
  - Associated with hydrothermal vents
    - warm-water vents, white smokers, black smokers



Evaporites

- Minerals that form when seawater evaporates
- Restricted open ocean circulation
- High evaporation rates
  - Halite (table salt)
    - NaCl
  - Gypsum and its "dry" equivalent Anhydrite
    - $CaSO_4*nH_20$
    - $CaSO_4$

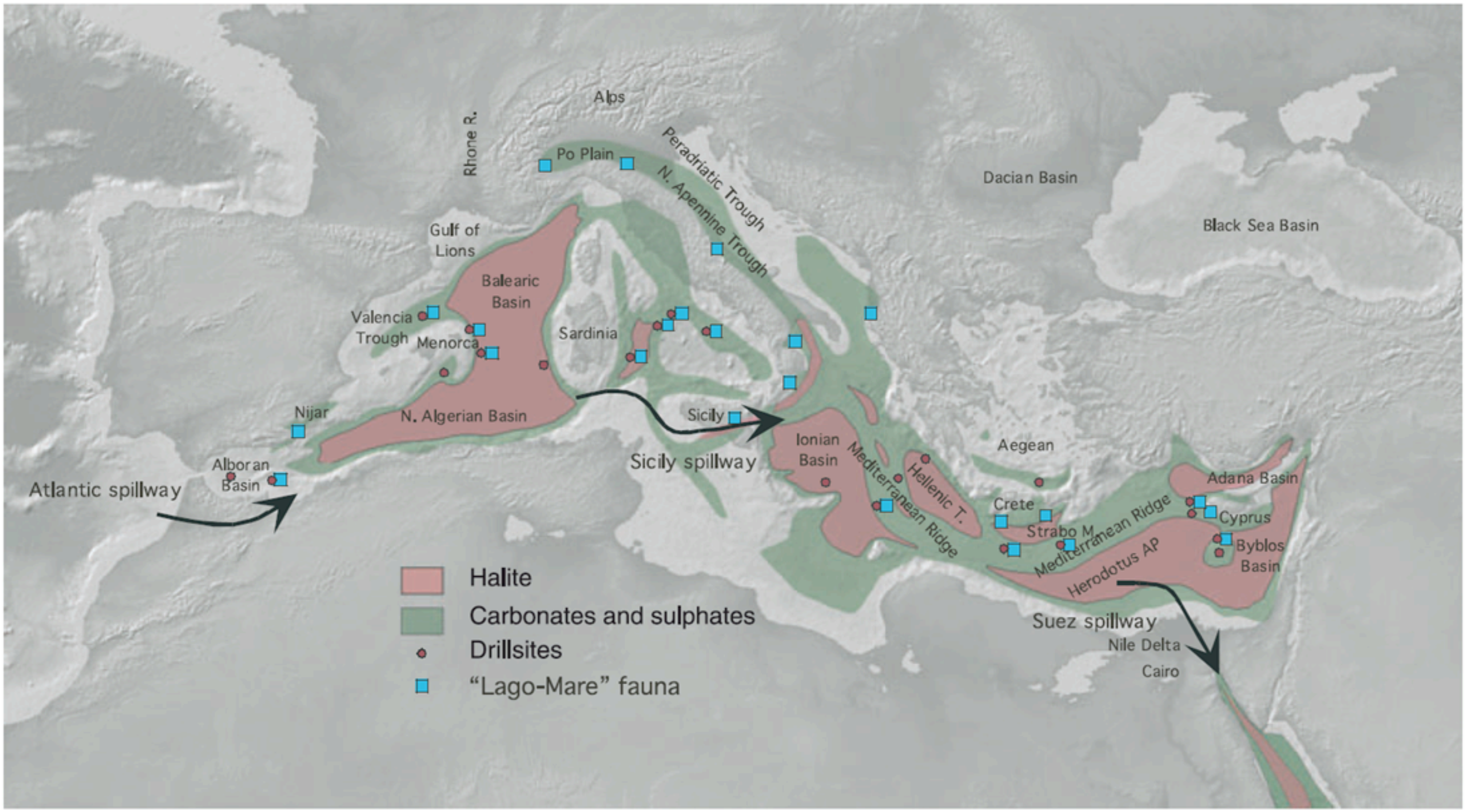




Above: a model for the deposition of Permian evaporites in Texas

Below: a model for the sabkha environment of today's Arabian peninsula

Mediterranean Salinity Crisis (Miocene)



Evaporites: gypsum

Gypsum rock from the Miocene Mediterranean Salinity Crisis
Northern Apennines, east of Bologna, Italy

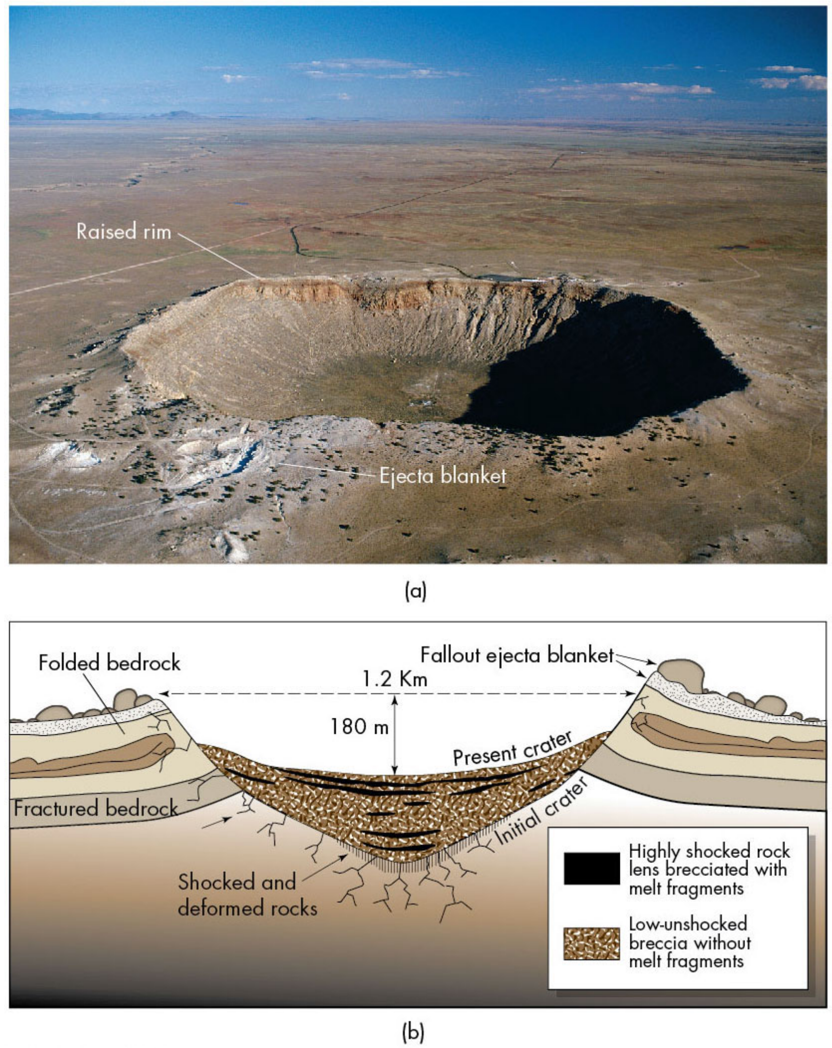
Evaporites: halite

Left: Halite (and other less common evaporites) and salt brines from Trona, California

Right: Halite structures and crystals from Death Valley, California

4.5 – What Are the Characteristics of Cosmogenous Sediment?

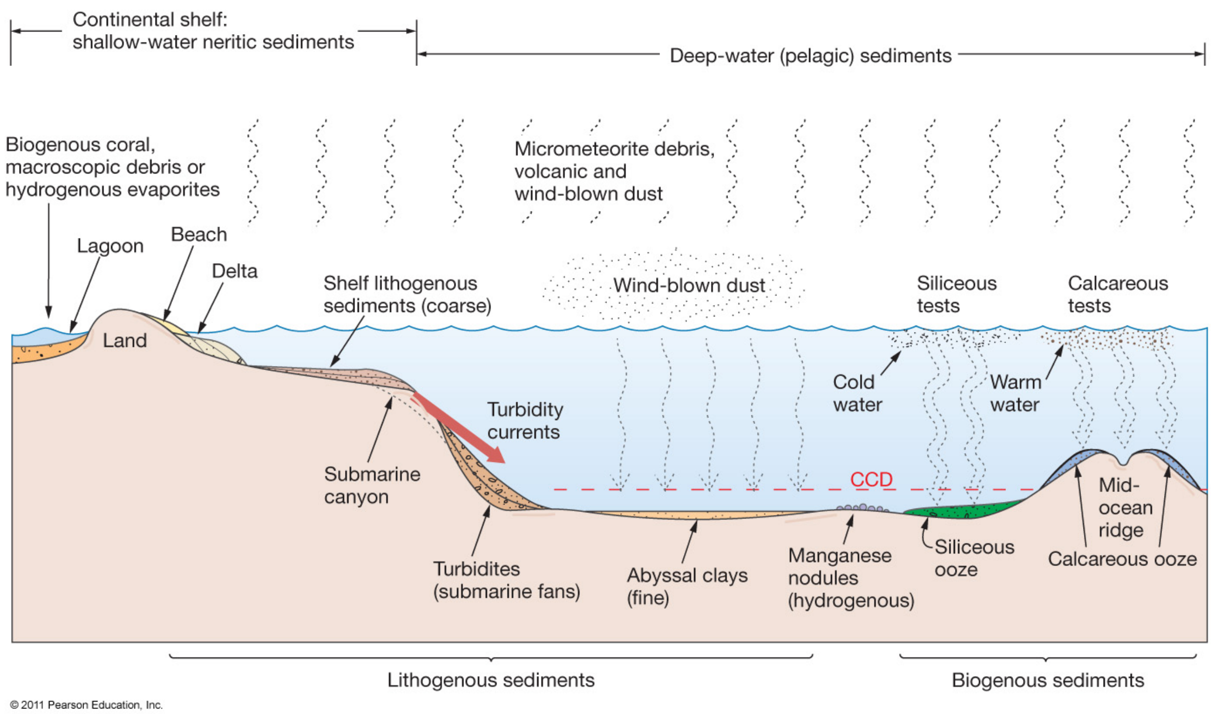
- Macroscopic meteor debris
- Microscopic iron-nickel and silicate spherules (small globular masses)
  - Tektites
  - Space dust
- Overall, insignificant proportion of marine sediments
- Meteor debris (meteorites) has been identified on land around impact craters



Meteor Crater, Arizona

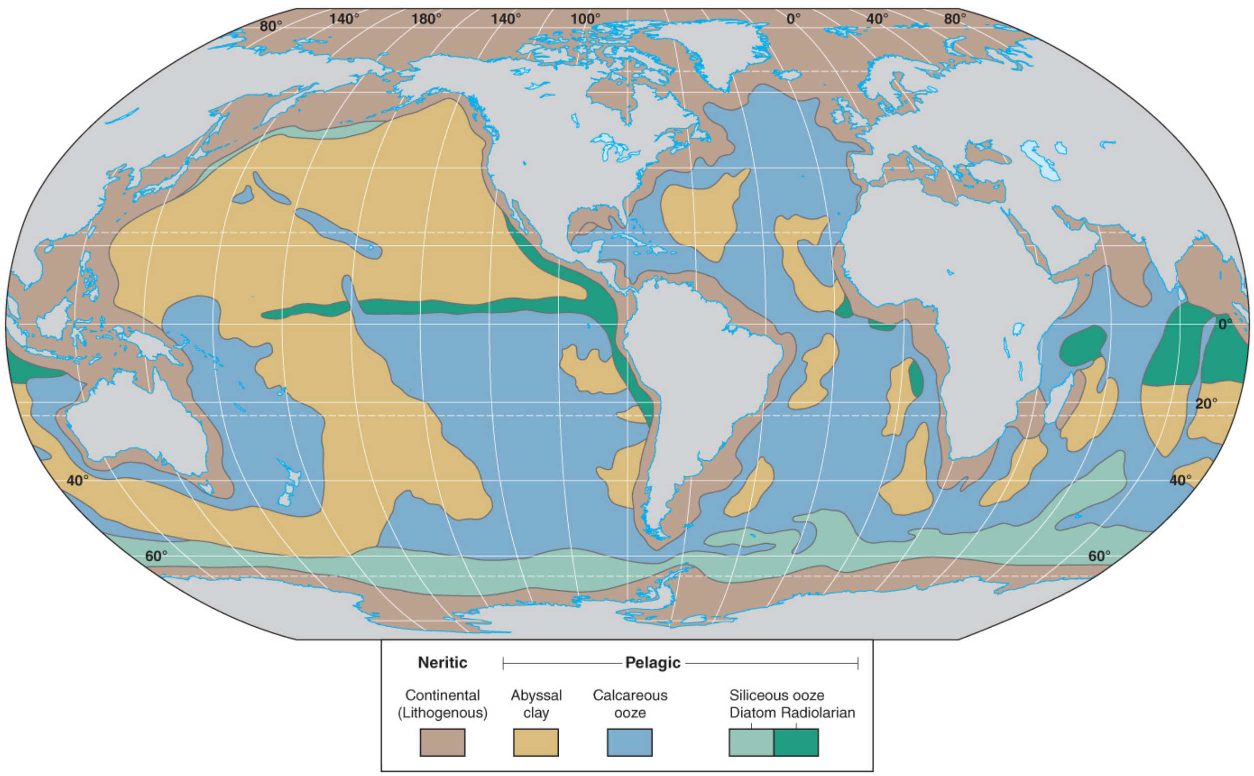
4.6 – How Are Pelagic and Neritic Deposits Distributed?

- Most deposits occur as mixtures
- Typically one sediment type dominates in different areas of the sea floor



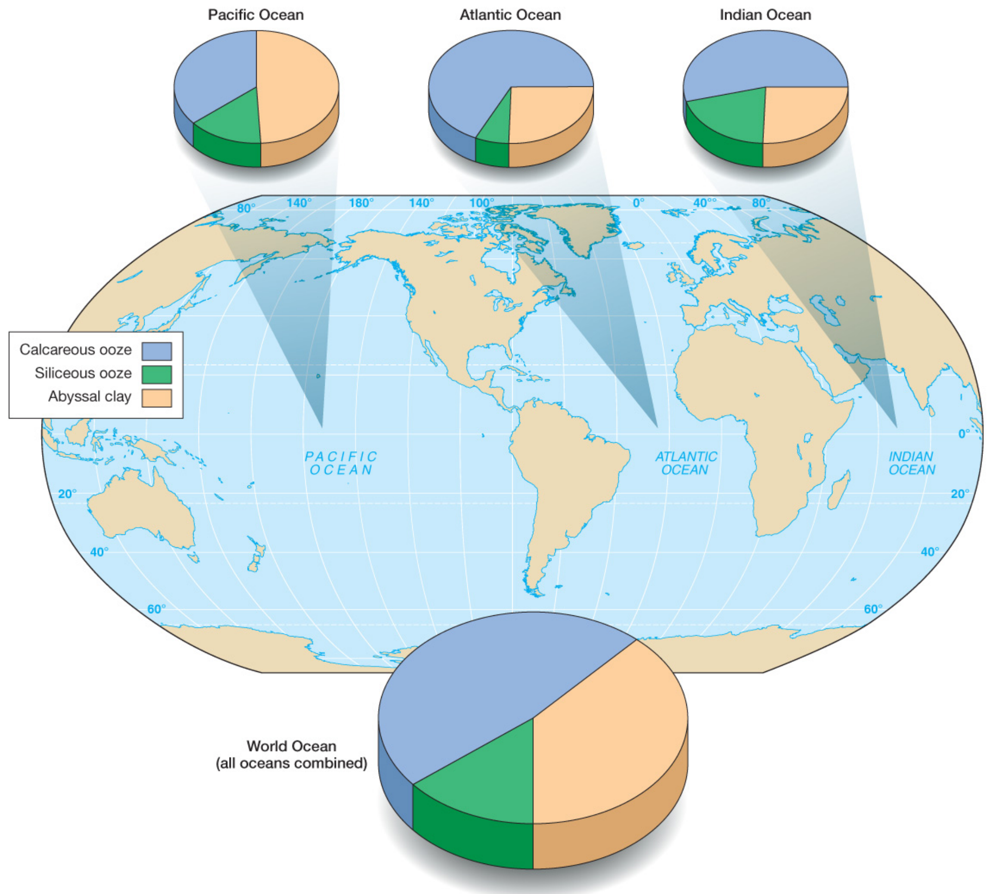
Pelagic and Neritic Sediment Distribution

- Neritic sediments cover about ¼ of the sea floor.
- Pelagic sediments cover about ¾ of the sea floor.



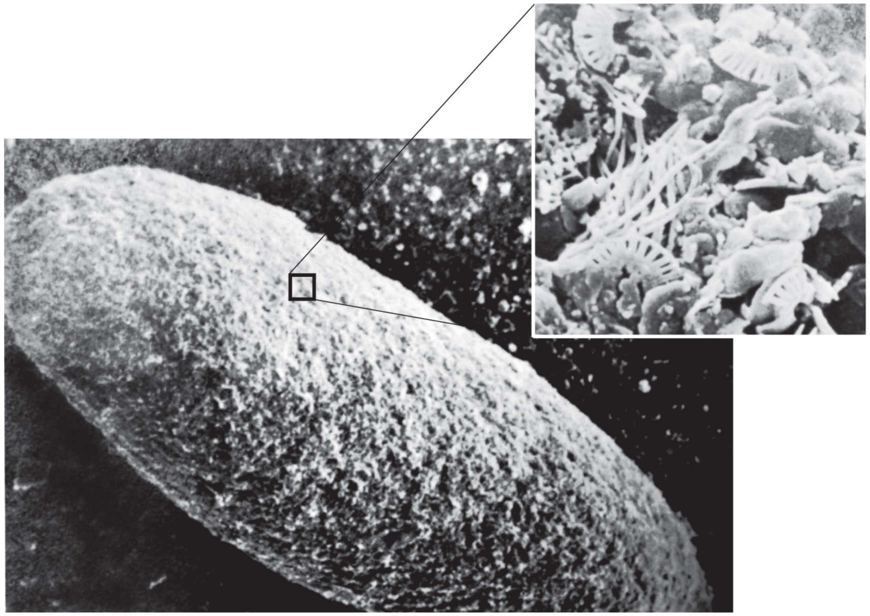
Pelagic and Neritic Sediment Distribution

- Controlled by:
  - Proximity to sources of lithogenous sediments
  - Productivity of microscopic marine organisms
  - Depth of water
  - Sea floor features

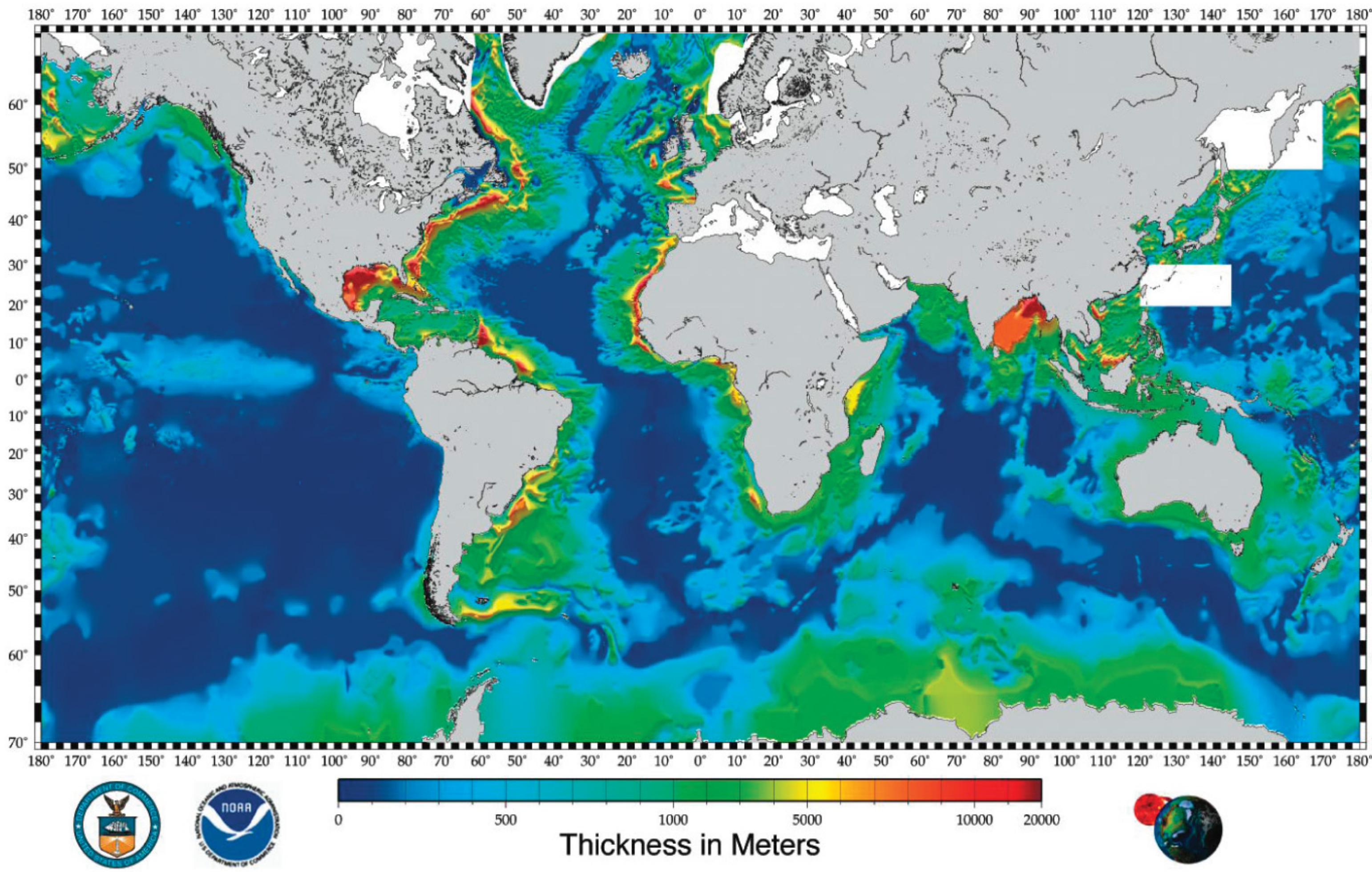


Sea-Floor Sediment Represents Surface Conditions

- Microscopic tests (coccoliths and other) sink slowly from surface ocean to sea floor (10-50 years)
- During this time, even a slow ocean current can can carry tests away (horizontally) for thousand of km
- Most biogenous tests clump together in fecal pellets
  - Fecal pellets large enough to sink quickly (10-15 days)



Worldwide Marine Sediment Thickness



4.6 – What Resources Do Marine Sediments Provide?

- Energy resources
  - Petroleum
    - Mainly from continental shelves
  - Gas hydrates

- Sand and gravel (including tin, gold, and so on)

- Evaporative salts

- Phosphorite

- Manganese nodules and crusts

Petroleum

- Petroleum (oil and natural gas) forms because of the preservation of organic matter in environments with scant or no oxygen

- Photosynthesis

solar energy

$6CO_2 + 6H_20 \rightarrow C_6H_{12}O_6 + 6O_2$

carbon dioxide + water → sugar + oxygen

- Respiration

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_20$

sugar + oxygen → carbon dioxide + water

release of (solar) energy stored in sugar

Petroleum

- Destruction vs. Preservation of Organic Matter
  - oxygen is needed to burn sugars
  - upon death, bodies are recycled by scavengers, decomposers, who all need oxygen
  - if there is no oxygen, organic matter (the sugars) do not decompose and are preserved, albeit modified
  - this preserved organic matter that escaped decomposition makes for hydrocarbons (oil and natural gas)

Petroleum

- Oil and natural gas are found within pores and/or fractures within rocks
- These rocks can exist on land or in the ocean
- A lot of reservoirs are found in shallow waters
  - Gulf of Mexico
  - Alaska, Russia, Arctic Waters
  - Southern California
  - North Sea
  - South East Asia
  - Adriatic Sea
  - east coast of South America
  - west coast of Africa

Gas hydrates (Clathrates)

- Compact chemical structures that form when high pressure squeezes chilled water and gas
- Common at the bottom of the continental shelf
- Mostly contain natural gas (Methane, CH_4), forming by metabolic activity of bacteria decomposing organic matter
- Very difficult to extract

Other Resources

- Sand and Gravel
  - dredged from continental shelf
- Evaporative Salts
  - gypsum (plaster)
  - halite (human consumption)
- Phosphorite
  - fertilizers
- Manganese Nodules and Crusts
  - metals, such as Cobalt (Co)
  - expensive, uncommon
- Rare-Earth elements
  - used for electronics
  - sometimes associated with deep-sea hot springs along mid-ocean ridges

Mining Sea Salt

Distribution of Manganese Nodules